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TITLE: **HIGH-TEMPERATURE, DEPLOYABLE, MEMBRANE HEAT PIPE RADIATOR ELEMENT; DEMONSTRATION AND STATUS**

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HIGH-TEMPERATURE, DEPLOYABLE, MEMBRANE HEAT-PIPE RADIATOR ELEMENT; DEMONSTRATION AND STATUS

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INTRODUCTION

Performance tests of a high-temperature, deployable, membrane heat pipe have been conducted. This system is intended for use in thermal rejection systems for space nuclear power plants. Because current developmental programs for space nuclear power require heat rejection systems in the 2 to 100-megawatt range, development of lightweight, large-area, heat rejection radiators with operating temperatures of greater than 600 K is being investigated. Heat-pipe radiators are potentially the lightest-weight closed-loop systems available in this power and temperature range. Current state-of-the-art radiator designs provide a specific mass in the range of 5 to 20 kg/m^2. Membrane heat-pipe designs, using alkali metals as the working fluids and metal foil for containment, offer the potential for a specific mass of about 1.8 kg/m^2 and a mass-to-power ratio of approximately 0.04 kg/kW at 1000 K. Because the membrane heat pipes are flexible, the radiator may be rolled up for compact storage and shielding between operating periods. Passive deployment is achieved by the internal pressure developed as the working fluid is brought to operating temperature and thus requires no linkages, actuators, or special-purpose elements. Upon deployment, the high-temperature radiator unrolls, like a party favor, to a fully extended position.

SINGLE SEGMENT HEAT PIPE DEVELOPMENT

A high-temperature, deployable, membrane heat pipe 100-cm long, with an 8-cm-wide radiator simulating a single segment in a flat array was fabricated and tested. Design operating temperature was 1000 K. Because of the operating temperatures, metal foil was chosen for containment and sodium alkali metal as the working fluid.

The containment and wick were made of 304 stainless steel. The membrane radiator containment material was 0.0127-cm-thick stainless steel foil. The fluid distribution system consisted of a homogeneous slab wick structure. Two layers of 100 x 100-mesh stainless steel screen were cut on a bias and joined to develop the wick. The evaporator was fabricated from stainless steel tubing. The heat input region was circular and the transition zone between the heat input and foil condenser was tapered from a circular to an oblong cross section.

Fabrication Procedure

The fabrication procedure was begun by cutting the 304 stainless steel foil into two rectangular sheets. Two strips of 100 x 100-mesh stainless steel screen (7.5-cm wide and 100-cm long) were cut on a bias to allow greater flexibility of the wick structure in the flexible condenser region. A series of spot resistance welds were used to join the two strips of screen to form the slab wick. The foil and wick were then chemically cleaned with a caustic solution. Joining the wick to one sheet of foil was accomplished by resistance welding with a bench seam welder. The remaining sheet of foil was then joined to the foil/wick assembly by seam welding the two foil sheets along the edges to form the condenser envelope.

A 5.1-cm diameter stainless steel tube with a 0.0889 cm wall thickness was used for the evaporator. It was maintained circular at the heat input region for ease of rf-induction heating. The remaining tube length between the heat-input zone and the foil condenser was tapered from a circular to an elliptic cross section to achieve a smooth transition to the foil condenser opening and thus reduce the amount of wrinkling of the foil in this region. A wire-cage structure was placed in the tube/foil-condenser cross-section interface to prevent the foil from being drawn into the evaporator while the heat pipe chamber was being evacuated. The foil condenser was joined to the thicker wall evaporator tube by fusion welding. The heat pipe was then leak checked with a helium-diffusion leak detector. When the system was helium-leak tight, an end cap and fill tube were joined to the assembly.

The heat pipe was vacuum degased by furnace heating at a temperature of 1175 K for approximately one hour, and then charged with a predetermined volume of sodium. The sodium was transferred to the heat pipe by distillation. The following operations were performed in sequence during the distillation process: 1) the heaters on the calibrated volume were brought to temperature allowing the sodium charge to melt, 2) the distillation pot was evacuated, 3) after the volume of sodium was molten, the valves were manipulated to allow the sodium to be driven, by argon gas pressure, from the calibrated volume to the distillation pot, and 4) the heaters extending from the distillation pot to the heat pipe were brought to temperature to allow sodium distillation into the evacuated heat pipe. Wet-in was accomplished by uniformly heating the heat pipe in a vacuum furnace at a temperature of 975 K for a period of approximately 48 hours.

TEST PROCEDURE AND RESULTS

The heat pipe was placed in a vacuum chamber in fully extended configuration. The circular portion of the evaporator was heated by placing it inside an rf-induction coil. Heat pipe operation at a temperature of 800 K was achieved by increasing the power input, in small increments, until the thermal melt front propagated from the evaporator to the end of the condenser. The power was then shut down and the system allowed to cool. The heat pipe was then removed from the vacuum chamber, and the radiator element was rolled to a diameter of approximately 20 cm and placed into the vacuum chamber in a fashion similar to the previous operation. Power input to the evaporator was increased in small increments. As operating conditions were approached, the thermal front propagated from the evaporator to the rolled radiator portion and deployment began in a smooth continuous fashion. The extended portion of the radiator assumed a cylindrical configuration. Deployment began at a temperature of 700 K and was completely extended at 800 K. Tests were conducted at a peak temperature of 1000 K. Smooth deployment of the membrane radiator may be attributed to the melting of the sodium bond along the propagating thermal front. In addition, the foil becomes more ductile in the heated region allowing the internal pressure of the fluid to expand the foil sheets. At peak power, the radiator element was dissipating approximately 3.0 kW to the environment. Power dissipation was determined from radiative transport between two diffuse concentric cylinders [1] as in

$$Q=\sigma A_{hp}(T_{hp}^4-T_{vc}^4)/[1/\varepsilon_{hp}+(A_{hp}/A_{vc})(1/\varepsilon_{vc}-1)], \qquad (1)$$

where the subscripts hp and vc refer to the heat pipe and vacuum chamber respectively.

There were no start-up anomalies apparent in the tests. Deployable heat pipes offer the advantage of effectively having a low L/D aspect ratio when initially in a rolled position; therefore a generally smooth start-up was expected. After full deployment of the membrane radiator, the system assumed normal heat pipe operation in steady-state conditions.

CURRENT AND FUTURE WORK

The focus of this study was the demonstration of passive deployment for a single-segment, high-temperature membrane heat-pipe. In practical designs, several individual units may be joined together to form a segmented array. A multisegment, deployable, high-temperature, membrane heat pipe radiator is currently being investigated. The system will be capable of dissipating 20 kW of thermal power and consist of three segments with overall dimensions of 30 cm in width and 183 cm in length. Heat input will be provided by rf induction heating. Metal foil for containment and an alkali metal as the working fluid will be used.

Analyses have shown that for the given geometry and power level in a microgravity environment, the fluid mass flow requirement can be satisfied with an artery/slab-wick combination for the fluid distribution system. The slab wick will be made of layers of 100 x 100-mesh stainless steel screen cut on the bias to allow for flexibility. Arteries will be formed by folding the ends of the slab wick and joining the lap to itself by resistance welding. A stainless steel cylindrical helix will be inserted into the artery to assure artery flexibility and prevent the artery walls from collapsing when the membrane radiator is rolled.

Containment for the membrane radiator will consist of metal foil such as stainless steel or nickel. Metal foils for radiator containment as thin as 0.0025 cm are being investigated. The artery/slab-wick fluid distribution system will be joined to the metal foil by resistance welding and the foil sheets will be joined by seam welding along the edges to form the radiator envelope. Because the extended portion of the radiator tends to assume a cylindrical configuration, the foil adjacent to the seam weld experiences an abrupt bend and is subject to large stresses. Alternative weld closure configurations are under investigation to reduce the weld stresses.

Joining the radiator envelope to the thicker evaporator wall will be accomplished by a combination of resistance and fusion welding. The evaporator will have a constant cross-section configuration with semicylindrical ends. This will allow for a smoother transition from the rigid evaporator to the flexible radiator and thus reduce the amount of wrinkling. A wire-cage structure will be placed in the evaporator/condenser cross-section interface to prevent the foil from being drawn into the evaporator during evacuation of the heat pipe chamber. The testing procedure will be similar to that of the single-segment radiator element described in this paper.

CONCLUSION

Passive deployment has been demonstrated for a single-segment, stainless steel, membrane heat-pipe radiator element, at a temperature of 800 K. The tests showed that the radiator element deployed in a continuous, uniform manner. Upon full deployment of the membrane radiator, the system assumed normal heat pipe operation in steady-state conditions at temperatures up to 1000 K. The tests indicate that operation of a full-scale, segmented model is achievable.

Membrane heat-pipe designs using alkali metals as the working fluids and metal foil for containment offer the potential for a specific mass of about 1.8 kg/m^2 and a mass-to-power ratio of approximately 0.04 kg/kW at 1000 K.

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